Contract No. 951263 Report No. TE-4055-94-67

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~~FIFTH~~ QUARTERLY REPORT

SOLAR THERMIONIC GENERATOR DEVELOPMENT

March 1967

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

Prepared for

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FIFTH QUARTERLY REPORT
SOLAR THERMIONIC GENERATOR DEVELOPMENT

Summary

This report covers progress for the fifth quarter, corresponding to the period from December 1, 1966, ~~to~~ February 28, 1967.

During this quarter, a second collector-radiator model was fabficated and tested to evaluate converter design modifications aimed at the reduction of collector temperature. This effect showed that the modified converter structure should be capable of maintaining collector temperatures below 1030°K at output currents up to 72 amperes. Previously, the collector temperature of converter T-205 had been observed to reach 1043°K at an output current of 49.3 amperes.

Other work performed under the program comprised the evaluation of vanadium as a braze material to join rhenium to niobium, and the comparison of the strength of nickel-gold eutectic braze with that of a palladium-silver-copper alloy for the joining of copper to molybdenum. These braze tests showed that vanadium is a suitable braze material for joining rhenium to niobium, and that the nickel-gold eutectic has far stronger adherence to molybdenum than does the palladium-silver-copper alloy.

1. Design of Converter T-206

The design of converter T-206, shown in Figure 1, involved several modifications to that of converter T-205, aimed at reducing the collector temperature. The collector barrel was shortened by 0.030 in., and the transition piece, part No. 10, joining the collector barrel to the radiator fins, was thickened by 0.070 in. To accommodate these two changes, part No. 5 was made shorter by 0.020 in. Furthermore, the area of the radiator fins was increased by adding 0.3 in. to their length. Finally, the design included a new cesium reservoir, partially coated with chromium oxide, capable of increased radiation heat loss and, therefore, lower operating temperatures. Because of the capability of the reservoir to dissipate more heat, the cesium tube, part No. 14, was changed to stock dimensions and therefore no longer required thinning down of the wall over a portion of its length.

The design was presented to JPL for approval, and JPL recommended that we demonstrate the ability of the design changes to effect a suitable reduction in collector temperature before proceeding with the fabrication of converter T-206. It was agreed that a suitable demonstration could be accomplished with the fabrication of a new collector-radiator structure that would reflect all the design features proposed for converter T-206.

2. Fabrication of the Collector-Radiator Model

Figure 2 shows the assembled collector-radiator model. The unit was instrumented with a brazed thermocouple 0.080 in. underneath the collector face, two thermocouples at the root of one fin,

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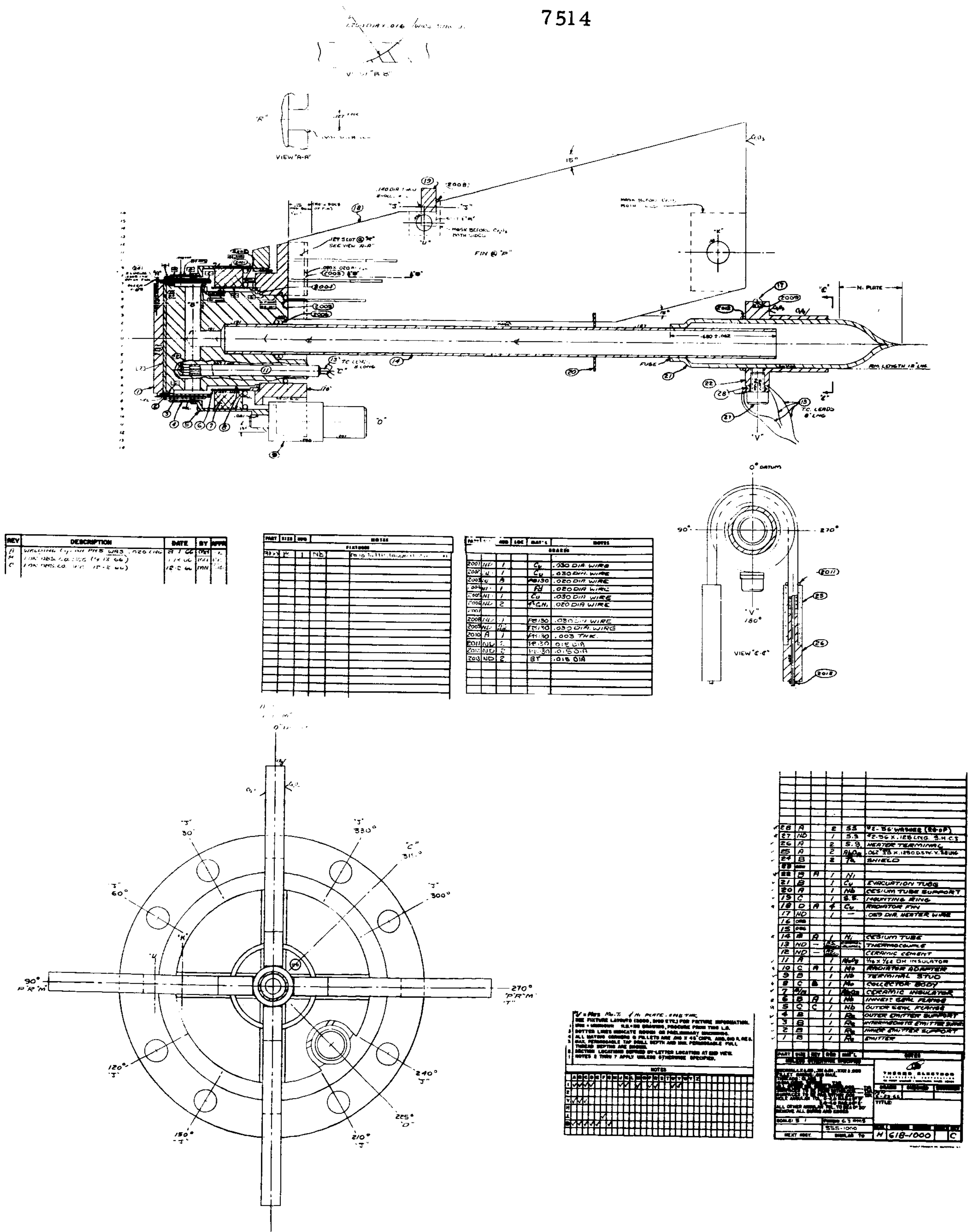

Figure 1

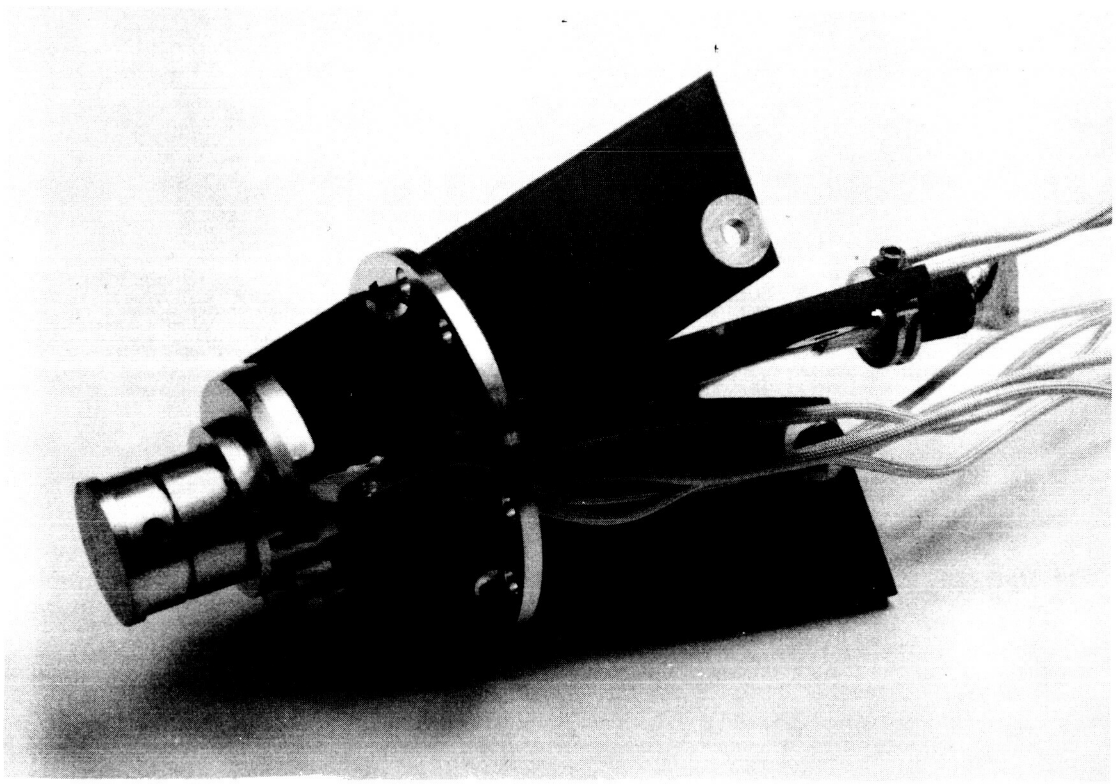

Figure 2

one thermocouple at the end of another fin, and one thermocouple on the cesium reservoir. No heater was brazed to the cesium reservoir. In order to ensure good contact between the radiator fins and the molybdenum base into which they are brazed, the fin braze was performed so that braze material could be added before the second braze operation. The resulting assembly showed one defect: The space between the inner seal flange, part No. 6, and the collector body, part No. 8, was partially filled with copper braze material that overflowed from the braze between the radiator adapter, part No. 10, and the collector body. Although the amount of braze was much too small to have caused any significant error in the heat transfer data, it could easily cause the failure of the ceramic seal in a fully assembled converter because it defeats the expansion isolation function of the seal flange. The possibility of this occurrence during converter fabrication can be minimized by reducing the amount of braze material used between the collector body and the radiator adapter.

3. Test of the Collector-Radiator Model

The Collector-Radiator #2 data sheet gives the temperature measurements obtained on the collector-radiator model at various heat inputs. The measurements are interpreted in Figure 3. The first step in the test procedure was to obtain the temperature distribution caused by filament heating alone, so that the magnitude of this heat input could be ascertained. The initial set of readings was obtained for a filament current of 17.5 amperes, which proved to be too low. For that reason, this measurement was repeated at the end of testing for a filament current of 22.8 amperes. The remainder of the test consisted of measuring the temperature distribution achieved at these discrete and carefully controlled values of electron-bombardment heat input. To avoid transient effects, the heat input was maintained constant at least 45 minutes before each reading of temperatures. The collector face was exposed to an electron-bombardment structure that operated at a temperature very closely equal to the collector temperature, so that the collector face was in radiation heat transfer equilibrium with the bombardment structure (excluding the filament), and its radiation heat losses could be neglected. From a comparison of the average radiator temperature achieved with filament heating alone with that achieved with filament heating plus electron bombardment, it can be shown that at 22.8 amperes of filament current, the filament heat input is 29.2 watts. Assuming that this input is proportional to the product of filament voltage and current, the following tabulation summarizes the heat transfer conditions obtained:

Data Point No.	2	3	4
Collector temperature, °K	843	1073	—
$V_F \times I_F$, watts	104	113	119
Filament heat into collector, watts	25.5	27.8	29.2
Electron bombardment power, watts	100.7	197.0	244.0
Total power input, watts	126.2	224.8	273.2
Average radiator temperature, °C	446	560	604
°K	719	833	877
Reservoir temperature, °K	525	569	587

Figure 3 shows the plots of collector temperature, average radiator temperature and cesium reservoir temperature vs collector heat transfer. As can be seen, no data was recorded for collector temperature at the highest value of heat transfer. This is because the temperature reading at the thermocouple decreased abruptly as the heat input

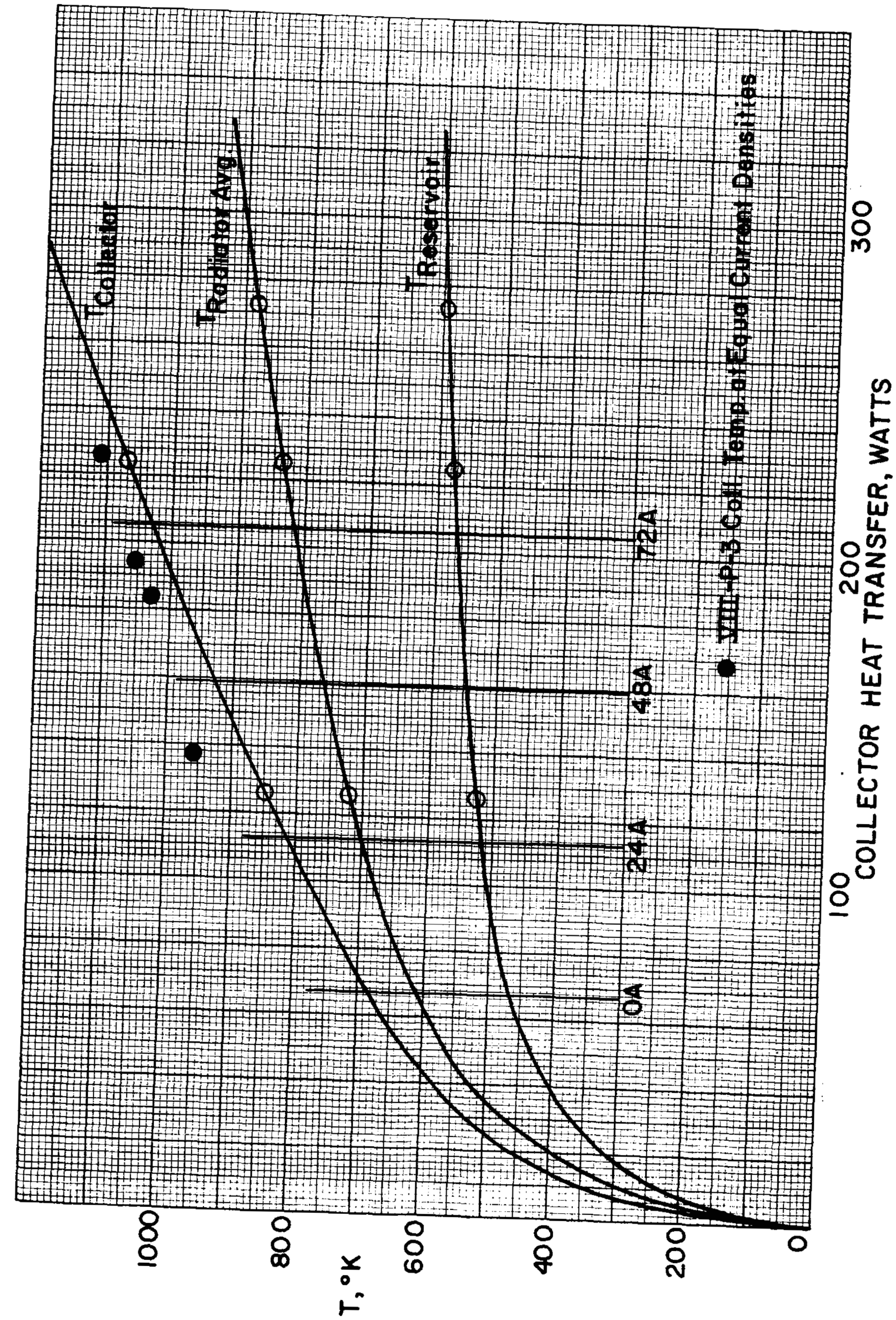
T Collector
T Radiator Avg.
T Reservoir
0A
24 A
48A
72A
VIII-P-3 Coll. Temp. at Equal Current Densities
T, °K
0
200
400
600
800
1000
100
200
300
COLLECTOR HEAT TRANSFER, WATTS

Figure 3

was raised between data points 3 and 4. Examination of the collector-radiator structure at the end of testing revealed that the collector thermocouple braze connection had melted and the thermocouple was no longer bonded to the place of measurement on the collector; therefore, its readings were inaccurate after loss of bond. The temperature at which loss of bond occurred, that is, above 800° C, is consistent with the softening point of the braze material used, T50, which is 779° C. Higher-melting-point braze materials were not used because they may dissolve the chromel alumel thermocouple material or alter its emf characteristics.

4. Discussion of Collector-Radiator Model Test Results

In order to interpret the collector-radiator model test results, it is necessary to calculate the output current values that correspond to various values of collector heat transfer. This has been done using the following assumptions, which were documented on pages 28 and 29 of the Fourth Quarterly Report submitted under this contract:

Cesium conduction loss	16.0 watts
Interelectrode radiation	34.4 watts
Additional internal radiation	2.0 watts

Furthermore, it was assumed that the emitter support radiates 15 watts to the collector body (out of its total loss of 58 watts, see App. III of Task II Final Report, JPL 950671), and that this heat input all takes place at the collector face (a conservative assumption). Electron cooling losses were assumed to equal 2.72 watts/ampere, which, at output voltages of the order of 0.8 volt, corresponds to a collector electron heating of 1.92 watts/ampere. Adding these heat quantities, the collector heat transfer predicted for various output currents is as follows:

Output current, amperes	Collector heat transfer, watts
0	67.4
24	113.4
48	159.4
72	205.4

The additional heat input to the radiator by conduction through the seal was assumed to be exactly offset by the cooling effect of the output leads. The collector-radiator model incorporated neither a heat-conducting seal nor output leads, and therefore its radiator heat transfer can be expected to have simulated that of an operating converter quite closely.

Figure 3 includes lines which correspond to the heat transfer values at 0, 24, 48 and 72 amperes of output current. As can be seen, collector and reservoir temperatures of 1030°K and 565°K, respectively, correspond to the highest output current value of 72 amperes. To ascertain that satisfactory converter operation can be achieved with these values of temperature, the temperatures were compared with those observed in converter VIII-P-3 of JPL 950671, Task I, which is representative of a well-optimized design. Since this converter has 20% less emitter area, the output current value corresponding to 72 amperes is 57.6 amperes. All available data shows that VIII-P-3 reaches this output at an optimum reservoir temperature exceeding

317°C, i.e., 590°K. The observed reservoir temperature of 565°K in the collector-radiator model is therefore low enough to allow ample opportunity to optimize reservoir temperature with the electrical heater on the reservoir. The original data on converter VIII-P-3, presented in the Third Quarterly Report, JPL 950671, Task I, shows that an output current of about 57.6 amperes the collector temperature, without collector heating, stabilizes to the following values:

Data Sheet	Data Point	I_o, amperes	T_{coll}, °C	T_o, °C	P_{eb}, watts
11	10	56.0	809	1677	385
14	3	62.0	838	1677	400
21	8	57.5	823	1700	420
23	8	68.5	861	1700	430

The converter was then handled to install thermocouples on the seal and the emitter output lead, and the Fourth Quarterly Report of that same program shows the following data:

Data Sheet	Data Point	I_o, amperes	T_{coll}, °C	T_o, °C	P_{eb}, watts
29	5	55.0	759	1700	410
30	7	55.5	767	1700	410

Thus a substantial drop in collector temperature (of the order of 50°C) was observed between the converter runs, and it may be suspected that the bond of the collector thermocouple of VIII-P-3 failed in a manner similar to that of the collector-radiator model. This is likely because the same braze material was used in both devices. The JPL data offers further evidence of such a failure: The 1700°C data of 8-31-64 shows that, at an output of 54.0 amperes and with a power input of 350 watts, the observed collector temperature was 700°C. Thus it seems reasonable to conclude that the collector temperature of VIII-P-3 for the output of 57.6 amperes was in excess of 809°C or 1082°K. Then the collector temperature of 1030°K achieved by the collector-radiator model at the equivalent output current of 72 amperes is more than 50°C below the desired value, and consequently the design of the new collector-radiator structure should be fully adequate for converter T-206.

5. Vanadium Braze of Rhenium to Niobium

One of the difficult joints to perform in the fabrication of T-200 converters is that of the re-entrant rhenium emitter structure to the niobium seal flange. Currently this joint is achieved by a low-penetration electron-beam melting of the niobium around the rhenium. The joint is difficult to make because it is critically important to avoid melting the rhenium. Otherwise a brittle intermetallic results, and the structure will not be leaktight. To avoid these problems, the use of vanadium brazing has been evaluated for the joint. Figure 4 shows the braze obtained with an 0.015"-dia. wire. Tear tests on the joint have shown that the joint is sound and that both the rhenium and the niobium remain ductile. This technique will therefore be used in the fabrication of subsequent converters, including T-206.

6. Evaluation of Alloys for Copper-to-Molybdenum Brazing

One of the weak areas found in previous T-200 converters is the braze of the copper fins to the molybdenum radiator adaptor. The weakness lies in that quite often the amount of braze material used, a nickel-gold eutectic alloy, is not sufficient to establish a metallurgical bond over the entire contact area available between the copper and molybdenum pieces. If more braze material is used, experience has shown that an overflow of braze alloy occurs at undesired locations without necessarily improving the copper-molybdenum bond obtained. Thus it appears that the only method available to improve this bond is to subject the assembly to a repeat braze with either the same or a different braze alloy. A different braze alloy offers the potential advantage that it may have a lower melting point, and therefore permit lowering the temperature to which the assembly needs to be heated in the second braze operation, so that a more reliable fabrication can be achieved. It is necessary, however, for this second braze alloy to possess good flow characteristics; otherwise a good thermal bond will not be obtained in those areas where addition of braze material is attempted. Figure 5 shows the results of a test conducted to compare the strength of the bond obtained using the conventional nickel-gold eutectic with that obtained with an alloy containing 10% palladium, 58% silver, and 32% copper. This alloy is commercially available under the trade name Engaloy 491, and it has a solidus-liquidus temperature range of 825 to 852° C.

In the test one pair of diametrically opposed fins were brazed with nickel-gold eutectic, and a second pair was brazed in a second braze with Engaloy 491. After the unit was completed it was visually inspected,

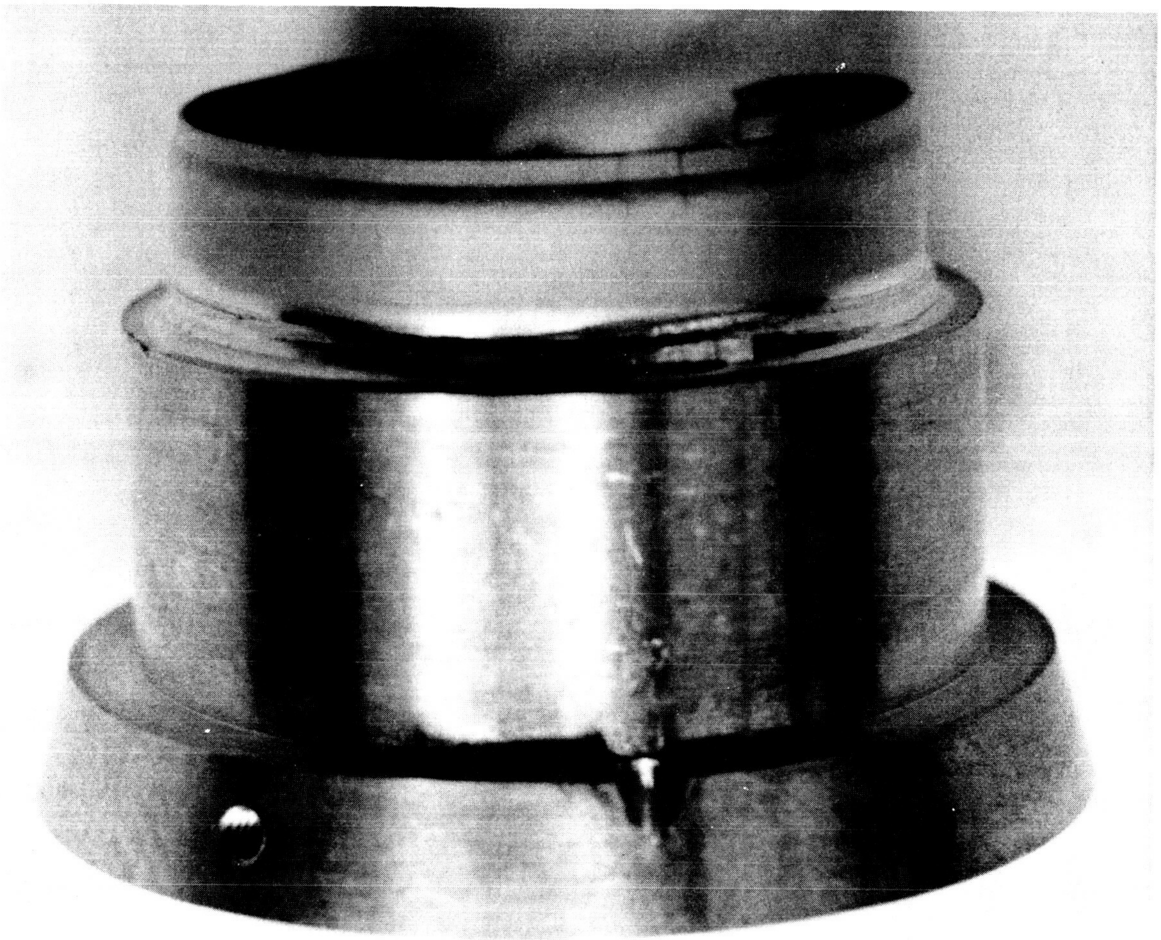

Figure 4

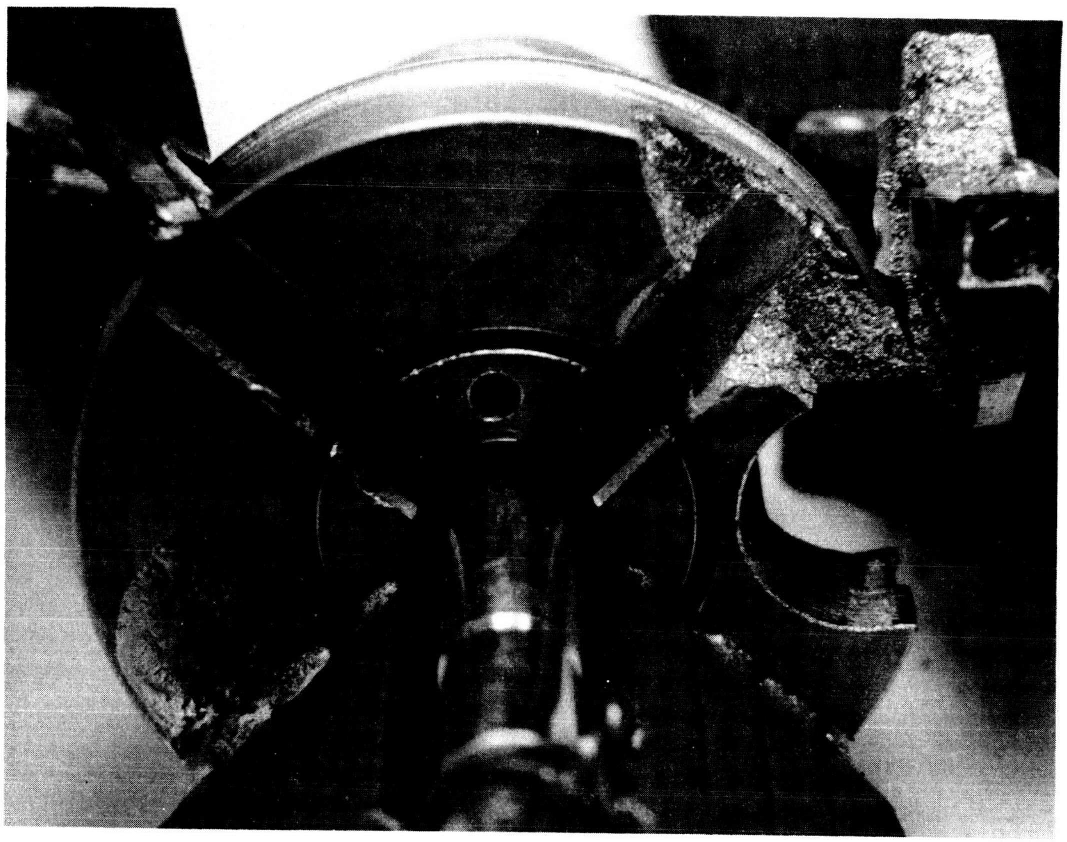

Figure 5

and it appeared that the Engaloy 491 had not wetted the molybdenum so well as the nickel-gold eutectic. Subsequent mechanical-pull tests showed that, in fact, Engaloy 491 does not adhere to molybdenum. One of the fins brazed with the nickel-gold eutectic was pulled, and the assembly broke right through the molybdenum bulk in preference to separating at the brazed interface. Figure 5 shows the appearance of this fracture, and, as can be observed, the inner molybdenum part corresponding to a collector barrel was not brazed. This attributed to the collector barrel time-lag involved in bringing the assembly to braze temperature, and the resulting lower temperature of this part when braze flow occurred. In actual converter fabrication this problem can be easily avoided by the use of slower heating rates.

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Sheet 1 of 1

Converter No. COLLECTOR RADIATOR #2 Run No. 1 Observer P. Brosens

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date 1967		1-12	1-12	1-12	1-12	[illegible]					
Time		[illegible] 03	13 55	14 43	5:32	9:33					
Elapsed Time, Hours		—	—	—	-	—					
T_O, °C		-		—		-					
T_O Corrected, °C		—		-	-	—					
$\Delta T_{Bell\ Jar}$, °C		—		—		-					
T_H, °C		-		-		—					
ΔT_E, °C		—		—	-	-					
T_E, °K		—		—	—						
V_O, volts		—		—		-					
I_O, amps		—	-	—	-	—					
P_O, watts		—		—							
I-V Trace No.		—	—	—	—	—					
T_R 10	mv	3.69	10.25	12.05	12.82	6.50					
	°C	91	252	296	314	159					
	°K	364	525	569	587	432					
T_C 14	mv	4.61	23.63	33.28	*	9.58					
	°C	112	570	800	—	236					
	°K	385	843	1073	—	509					
T_C base inner 13	mv	4.55	19.50	25.21	27.50	9.45					
	°C	111	473	607	661	233					
T_C base outer 12	mv	4.51	19.38	25.00	27.32	9.44					
	°C	110	471	602	656	233					
$T_{Radiator}$ 11	mv	4.45	17.26	21.35	22.68	9.05					
	°C	108	420	517	548	223					
V_{eb}, volts		0	1003	982.2	974.5	0					
I_{eb}, mA		0	100.4	200.6	249.9	0					
$E_{Filament}$, volts		3.6	4.8	5.0	5.2	5.2					
$I_{Filament}$, amps		17.5	21.6	22.5	22.8	22.8					
$I_{Coll.\ Heater}$, amps		—	—	—	—	—					
$I_{Res.\ Heater}$, amps		—	—	—	—	—					
Vacuum, 10^{-6} mm Hg		3.4	6.8	6.3	5.5	3.5					
Measured Efficiency, %		—	—	—	—	—					

NOTES: EB Power, w 0 100.7 197 244 0

* Thermocouple emf dropped because braze melted.